



NAL MEDICAL APPLICATIONS FACILITY:
BEAM TRANSPORT LINE,
REVIEW OF SOIL FOR THE 200 MeV SHIELDING REQUIREMENTS

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A. INTRODUCTION

This estimate of radiation shielding requirements is based on actual measurements made by C. Distenfeld¹ at Brookhaven. 200 MeV protons were stopped in a water tank eight feet deep and thirty feet high.

The formula given by Distenfeld for the Maximum Absorbed Dose Equivalent (MADE) is,

$$\text{MADE} = 9.76 \times 10^{-11} I t [\exp (-s/1.91)]/s^2 \text{ mrem}$$

which may be rewritten,

$$\frac{d \text{ MADE}}{dt} = 3.51 \times 10^{-7} I [\exp (-s/1.91)]/s^2 \text{ mrem/hr}$$

and where S = distance in feet from loss point to the point of interest and also thickness of water shield, measured perpendicularly to the beam direction,

I = number of protons stopping per second, t = time in seconds and 1.91 is an attenuation length in feet.

Now, some assumptions must be made,

- 1) The number of neutrons and energy spectra of neutrons produced in water and in magnets at 90° , is about the same. This is not a terribly bad assumption.²
- 2) The mean-free paths of all neutrons involved in this dose transport process is the same in water and in soil if measured in units of g/cm^2 . This is reasonable since soil is mostly oxygen.³

Then we can replace in the denominator of the exponent 1.91 by $1.91/2.0 = .955$, where the soil density is taken as 2.0 g/cm^3 .

Distenfeld¹ has normalized this formula at 1 ft up from the beam line. In the final rewriting of the formula, corrections have been made for the change of water for soil and normalization. The geometric factor obviously remains then,

$$\frac{d \text{ MADE}}{dt} = 3.51 \times 10^{-7} I [\exp (-s/.955)] / s^2 \text{ mrem/hr}$$

Application to the NAL-MAC.

A current of 10^{14} p/sec is estimated to be required for production of a clinically useful neutron beam. Losses of 1% at each man-hole are assumed. Then we can calculate the dose equivalent rate as a function of soil thickness as follows,

$$\frac{d \text{ MADE}}{dt} \approx 3.51 \times 10^7 [\exp(-s/.95_5)]/s^2 \text{ mrem/hr}$$

where now S = feet of soil

S feet	$d \text{ MADE}/dt$ mrem/hr
8	125.
10	10.
11	2.9
12	.85
13	.25

Hence, for a MADE of ~ 1 mrem/hr, 12 ft of soil is required if the beam losses are 10^{12} p/sec at any one point.

- i. Geometric shortening of the cascade due to the greater density and average mass number of the soil than water. This ought to be almost insignificant for shield thicknesses greater than 10 ft.
- ii. The details of the cascade are ignored in the first radial foot of shielding. This may, at most over estimate the MADE by $\sim 3/2$.

Conclusion.

The adoption of a soil shielding with a thickness of 12 feet from the top of beam pipe to the finished grade is justified if a dose rate of 1 mrem/hr is allowed in an uncontrolled area under expected normal running conditions.

References.

1. D. Distenfeld, Shielding Measurements - 200 MeV Linac, BNL-18025 (July 10, 1973).
2. R. G. Alsmiller et al, Analytic Representation of Non-Elastic Cross Sections..., ORNL-4046 (April, 1967).
3. M. Awschalom, et al., Chemical Composition of Some Common Shielding Materials, NAL-TM-168 (May 2, 1969).